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1. REPORT DATE <b>2007</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-2007 to 00-00-2007</b>	
4. TITLE AND SUBTITLE <b>Measuring Undersea Noise from Breaking Waves</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Naval Research Laboratory, 4555 Overlook Avenue SW, Washington, DC, 20375</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>3</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

## Measuring Undersea Noise from Breaking Waves

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**Introduction:** Breaking waves are ubiquitous on the Earth's oceans and play an important role in air-sea interactions, which are important to global climatological effects. Of particular interest to the Navy, breaking waves can be a dominant source in the undersea ambient noise field. Although breaking waves have been known to be the source mechanism of this sound for some time, most predictive models have been limited to simply associating sound levels to wind speeds. Recently NRL has undertaken simultaneous measurements of the surface expression of breaking waves, via radar and video, and their subsequent acoustic emissions to understand the relationships between characteristics (size, duration, etc.) of individual breaking waves and the generated acoustic noise spectra.

**Experimental Setup:** The Navy operates a range of offshore towers as a part of a Tactical Air Combat Training System (see Fig. 1). One of these towers, R2, serves as a platform from which we deployed a number of experimental sensors. The tower is located in the shallow waters (25 m) approximately 75 km off the coast of Savannah, Georgia, and extends 50 m above the water surface. The tower is equipped to supply power through solar panels, wind turbines, and a diesel generator. Additionally, it is equipped with two-way microwave communication back to shore. These features allow us to make long-term measurements while controlling the data acquisition from our offices at NRL via the Internet.

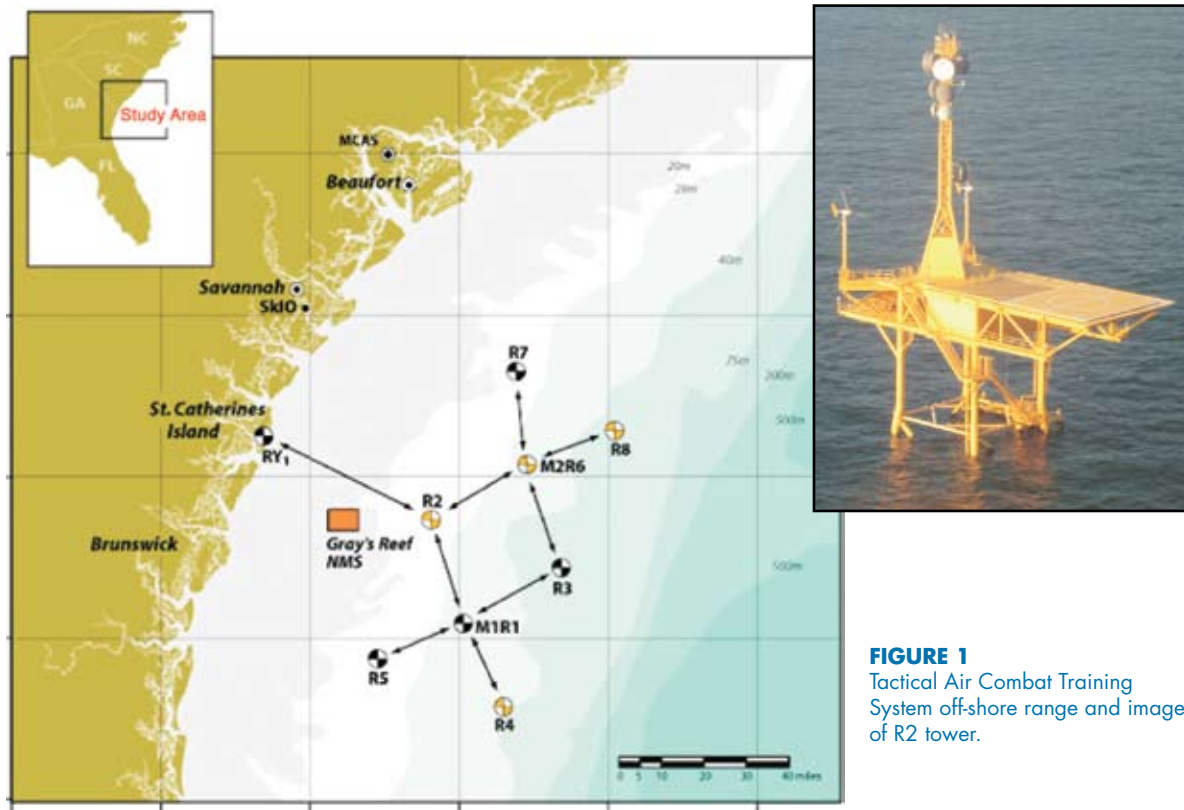
In early January 2006, we placed a bottom-moored vertical array of 32 hydrophones 100 m north of the tower. A cable connecting the array to the tower supplied power and transmitted the acoustic signals for acquisition. In addition to the hydrophone array, a high-resolution digital video camera and a dual-polarized, coherent, X-band radar were mounted on the tower to observe the ocean surface above the array.

**Acoustic-Video-Radar Associations:** To date, measurements have been made when wind speeds ranged from 5 to 21 m/s and when wave heights were between 1 and 3.4 m. The acoustic array data were processed to listen to the waves breaking directly overhead. Figure 2(a) shows an image from the video camera mounted atop the tower. The water surface above the array is visible along with the 20-m<sup>2</sup> helicopter pad. The region outlined in red represents a 100-m × 100-m area centered over the hydrophone array. The image pixels

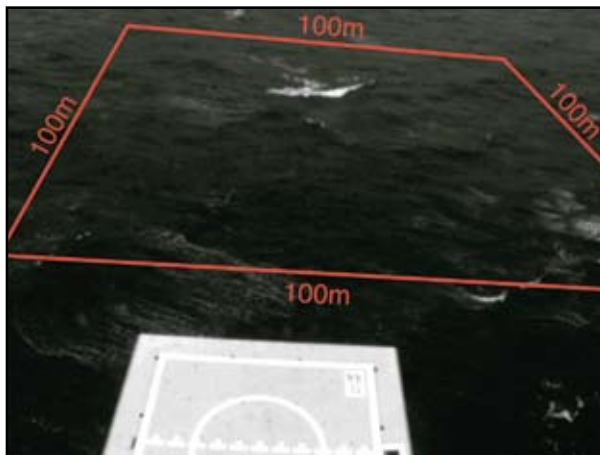
within this area are rectified (see Fig. 2(b)) to form a bird's-eye view such that quantitative measurements of the breaking waves can be obtained. We then used detection and tracking algorithms to capture the location and size of the actively breaking portions of individual breaking waves as a function of time. It is this active portion of the breaking waves that gives rise to acoustic radiation. Figure 3(a) shows a time-frequency surface of the sounds generated by the overhead breaking waves. Each breaking event produces a broadband burst of energy that lasts less than a couple of seconds. At the top and bottom of this figure, the occurrences of the breaking waves, as obtained through video processing, have been inserted as white lines. Although not perfect, a good agreement can be seen between the acoustic and video occurrences of breaking events. Further analysis will allow us to develop empirical relationships between the acoustic energy and the size of the surface expression of the breaking waves.

Comparison of the radar backscatter cross-sections from the two polarizations of the radar (transmit and receive antennas vertically polarized, VV; and transmit and receive antennas horizontally polarized, HH) allows the detection of sea spikes, which are radar backscatter events indicative of breaking waves. A sea spike is a scattering event for which the horizontal cross-section is greater than the vertical cross-section, so that their ratio,  $\sigma_{HH}/\sigma_{VV}$ , is greater than 1. A large body of research conducted over the past three decades has established a strong correlation between sea spikes and hydrodynamically nonlinear features, such as breaking waves, so the sea spike percentage can be used as a good, radar-based indicator of breakers. Similarly, we can process the video images to obtain a measure of the average active whitecap coverage of the actively breaking waves. Both measurements are analogous to the whitecap coverage ratio that is often reported as an indication of breaking wave activity. Both of these measures of breaking wave activity are plotted in Fig. 3(b) for a day in which the wind speed decreased from 13 m/s to 8 m/s. The blue dots show the average active breaking wave coverage obtained through video analysis. The red circles indicate the percentage of occurrences in which the cross-section ratio exceeds 1 for the same time period. Both of the measurements indicate the same general trend as the wind speed decreased over the day.

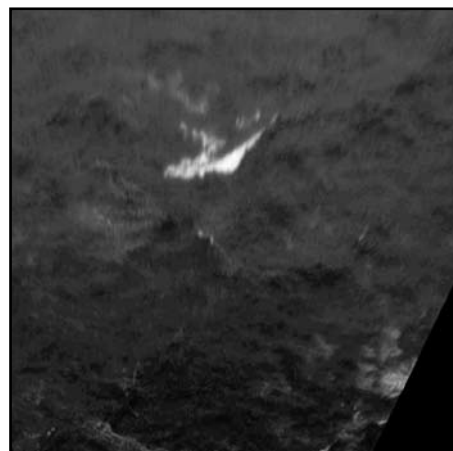
**Summary:** The capability to make long-term measurements of breaking waves allows us to obtain empirical relationships that will improve undersea noise predictions under a range of wind speeds and sea states. Additionally, the video measurements will serve to calibrate the radar measurements for better detection of actual breaking waves instead of sea spikes. The



**FIGURE 1**  
Tactical Air Combat Training  
System off-shore range and image  
of R2 tower.

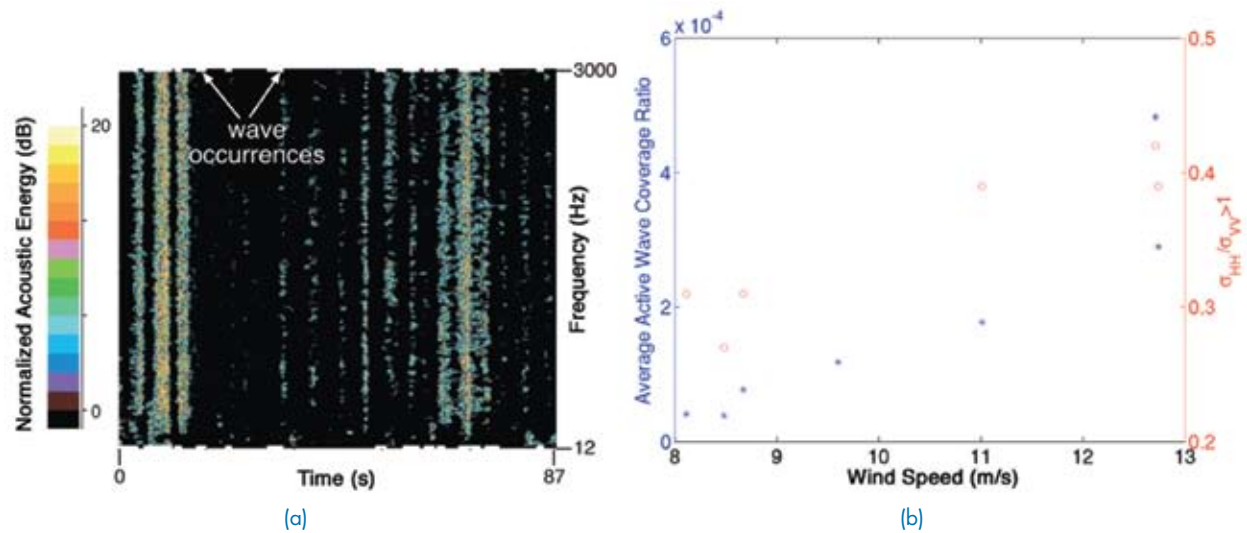


(a)



(b)

**FIGURE 2**  
(a) Video image snapshot from atop tower. (b) Rectified video image of individual breaking wave.

**FIGURE 3**

(a) Time-frequency surface of breaking wave-generated acoustic signatures and occurrences obtained from video. (b) Average active wave coverage ratio, obtained from video, and percentage of occurrences of sea spikes, obtained from radar backscatter.

improvement of breaking wave detection via radar will serve to improve our understanding of the importance of breaking waves in air-sea interactions.

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